NMP Environmental Monitor: Preliminary Design Concept

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Spacecraft Contamination and Coatings Workshop
Greenbelt, MD
October 29, 2003

INTRODUCTION

- Concept and Goals
- NMP ST8 and ST9 Technologies
- Historical Examples: SAMMES, RRELAX, IDS
- Environments and Sensors:
  - Contamination: QCM
  - Atomic Oxygen: Actinometer
  - Radiation: TID, SEU
  - Magnetic Field: Magnetometer
  - Temperature: Thermometer
- Conclusion and Plans

Environmental Monitor: CONCEPT

NMP is exploring the possibility of making an environmental diagnostic package available for inclusion on its validation flights.

The *raison d'etre* for this effort follows from the need to characterize the validation-flight environment so that future users can extrapolate or scale NMP test results to the end-use environment. Note: this monitor does not replace the need for the NMP experimenters to measure their specific parameters.

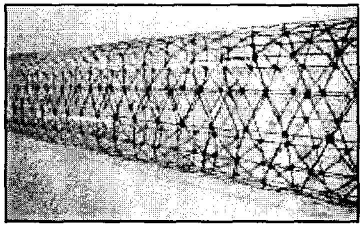
Short-Term Objective: To develop four hockey-puck size monitors to be included with the ST8 technology validation flights for a total cost of about $1M.

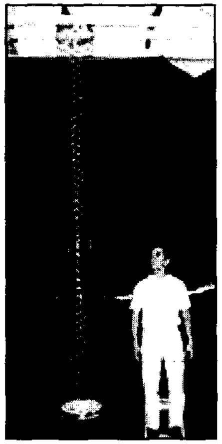
Long-Term Goal: To include an Environmental Monitor with every NMP validation flight from a commercial source for about $5,000 each.

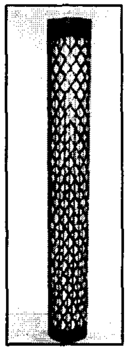
Goals: Environmental Monitor

1. MONITOR: Provide environmental data so future users can scale NMP test results to the end-use environment and to allow flight-to-flight comparisons. Data from this monitor are not intended to be used to update environmental models. Thus, the package is a monitor-grade not scientific-grade device.
2. SMALL: Monitor is to be the size of a hockey puck.
3. INEXPENSIVE: When developed and commercially available, the monitor should cost about $5,000 each excluding integration costs.
4. SAME (Near term): The monitor will be the same for all NMP flights. The package will not be customized for a particular NMP flight.
5. CUSTOM (Long Term): As this concept matures, the commercial provider(s) will be encouraged to develop variants.
6. COMMERCIALLY AVAILABLE: Want the monitor to be purchasable via a part number with specification sheet.
7. SUGGESTIONS: NMP is open to all suggestions.

ST8-1: Deployment of Ultra-Lightweight Booms







Flight Validation Objective: The objectives of an investigation directed to this technology area should be:

•Validation of boom deployment, including the dynamics and uniformity of the deployment action and the completeness with which the boom secures into its final state of deployment;

•Characterization of the structural mechanics and dynamics of the deployed booms; and

•Validation of design approach and predictive methods for deploying ultra lightweight booms by *correlating flight measurements with analytical models developed through ground testing*.

Measurements, Parameters, and Model Verification:
This in-space investigation will provide *relevant environment test results* that can be used to validate the performance models. Hence, the deployed subsystem should be adequately instrumented to verify successful deployment and to quantify predicted structural characteristics of the booms as follows:

- Deployment dynamics and reaction forces imparted to the experiment platform during deployment;
- Time required to execute the deployment (and *rigidization*, if inflatable);
- Power required over the deployment period;
- Deployed boom length, straightness, and uniformity;
- Mechanical stability in response to quasi-static loads and *temperature* changes; and
- *Structural dynamics*, including natural frequency, mode shape, and damping.

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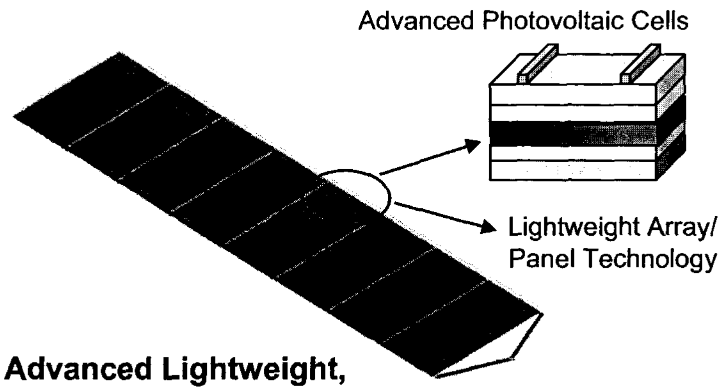
ST8-2: Deployment of Lightweight Solar Array



Advanced Lightweight,

High Performance Solar Array

***Flight Validation Objectives*:** The overall objectives of an investigation directed to this technology area should be:
•Characterization of the deployment, controllability, and structural dynamics of a lightweight solar array assembly;
•Verification of the predicted structural and *photovoltaic performance* of the deployed solar array, including the *behavior and durability of the photovoltaics, any supplemental optics, and panel materials in the space environment;*
•Verification of secure deployment after the solar array is deployed;
•Verification that the deployed solar array is dynamically stable;
•Validation of photovoltaic cell, blanket, and solar array technology that is capable of being qualified for future NASA missions; and
•Validation of all structural and electrical performance models used to scale up to 7 kW (if flight demonstration is subscale and/or not fully power producing).

Measurements, Parameters, and Model Verification: The principal objective for this in-space experiment is to provide relevant environment information that can be used to *validate the performance models*. Hence, the deployed subsystem should be adequately instrumented to verify successful deployment and to quantify predicted power generation characteristics of the array. The instrumentation should measure parameters that characterize the solar array performance in terms of:

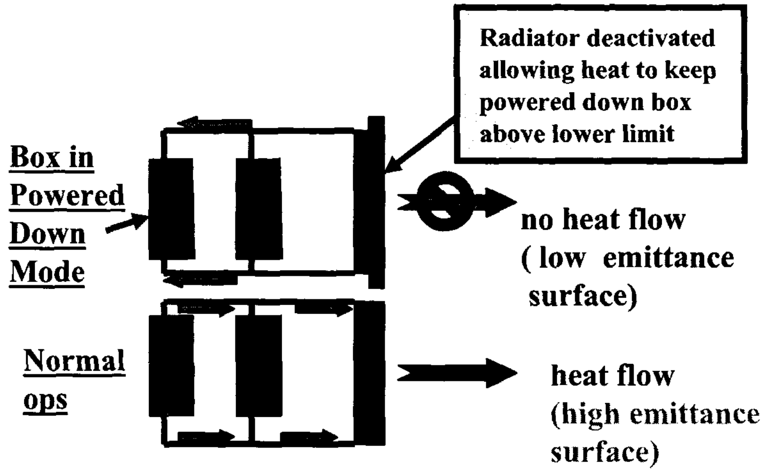
•Deployment dynamics and reaction forces imparted to the experiment platform during deployment;

•Structural dynamics of deployed array, including natural frequencies, mode shapes, and damping;

•Dimensional stability and change in array pointing angle in response to *temperature* changes; and

•Variation of voltage and current output as a function of time, temperature, and environmental conditions as measured at the spacecraft.

ST8-3: Thermal Management Subsystem for Small Spacecraft



Flight Validation Objectives: The objectives of an investigation directed to this technology area should be:

- Validation of the performance of a thermal control subsystem designed specifically for small (< 150 kg) spacecraft having a total power generation of ≤250 W and corresponding power dissipation of ≤200 W
- Validation of analytically predicted savings in spacecraft mass, power, and volume of thermal control system designed for small spacecraft when compared with conventional thermal control techniques; and
- Validation of analytical models used to predict thermal performance of optimized component locations enabled by new thermal control system.

Measurements, Parameters, and Model Verification: The thermal management subsystem is to be instrumented to the extent required to quantify all necessary parameters that characterize subsystem performance, including but not limited to:

- Component power dissipations;
- Component *temperature*, including temperature measurements of spacecraft surfaces that may affect the performance of the subsystem; and
- Any electrical power associated with control of the subsystem.

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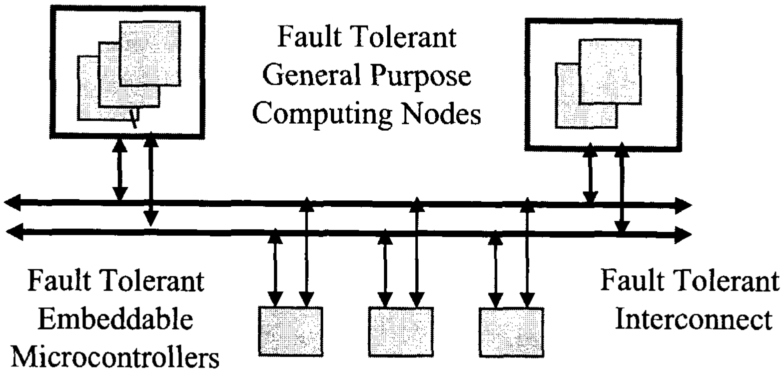
ST8-4: COTS Based High Performance Computing



***Flight Validation Objectives*:** The general objective of this experiment is to verify the feasibility of flying a high performance COTS-based data processing system onboard NASA spacecraft. Specific objectives are:

Validation of the radiation fault models, system models, laboratory testing procedures, design tools and fault tolerance techniques with respect to system level predicted fault rates and representative locations in *natural space radiation environments*; and

Validation that low cost fault tolerance techniques can provide predictable and acceptable levels of reliability for space based COTS onboard data processors while maintaining orders of magnitude performance improvement over state of the art radiation hardened systems in a minimal overhead, scalable architecture.

Measurements, Parameters, and Model Verification: The ultimate goal of this investigation is to validate and/or calibrate the underlying technology models proposed for this experiment, as well as to validate the efficacy of the fault tolerance techniques and system design methods and tools. In order to accomplish this, the following parameters are suggested as a minimum set to be measured by the investigation:

•Fault rates;

•Fault locations where fault sites are identified with sufficient physical (hardware) granularity to aid in diagnosing the system;

•*Radiation environment*;

•Number of successful recoveries from recoverable faults;

•Recovery time; Number of system failures which cause the system to cease operating due to unrecoverable faults; and

•Effective MIPS/Watt at the system level in the presence of recoverable faults.

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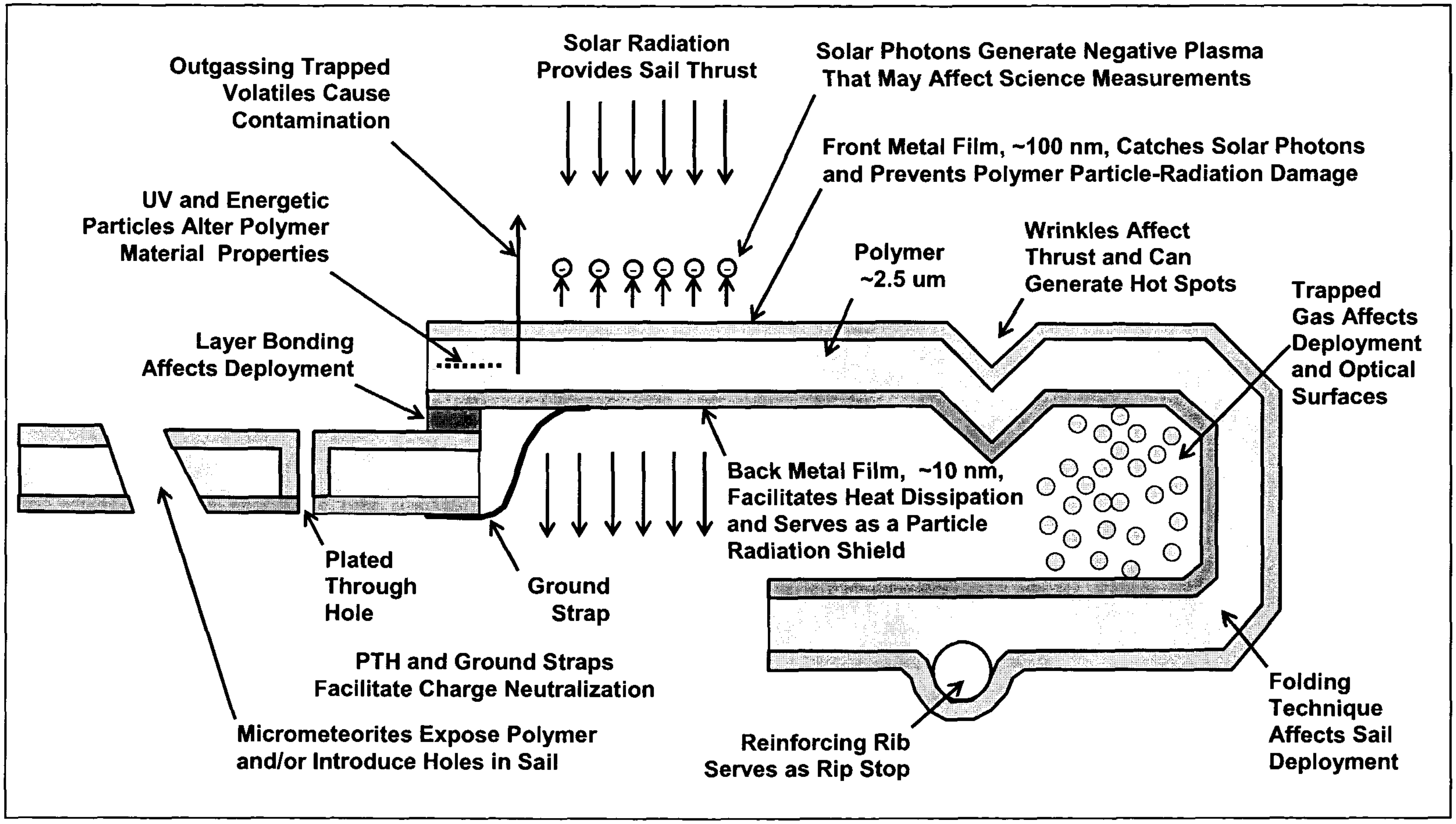
NMP Technologies and Space Environment

Environment	ST8-1 Ultra-Light-weight Booms	ST8-2 Light-weight Solar Arrays	ST8-3 Thermal Managem ent	ST8-4 COTS Computin g	ST9-1 Solar Sail	ST9-2 Aerocaptu re	ST9-3 Large Space Telescope	ST9-4 Precision Landing	ST9-5 Precision Formation Flying
1.0 Contamination									
1.1 Outgassing	X	X	X		X	X	X	X	
1.2 Thruster		X	X		X	X	X	X	X
2.0 Radiation									
2.1 Electrons	X	X		X	X		X		X
2.2 Protons	X	X		X	X		X		X
2.3 Cosmic Rays				X					X
2.4 UV	X	X		X	X		X		
2.5 Plasmas	X	X			X	X			
2.6 Neutrons				X					
2.7 Magnet Field	X	X		X	X		X		
3.0 Particulate									
3.1 Orbital Debris		X	X		X		X		X
3.2 Micrometeorites	X	X			X		X		X
3.3 Atomic O	X	X			X		X		X
4.0 Temperature									
4.1 High T	X	X	X	X	X	X	X		X
4.2 Low T	X	X	X	X	X	X	X		
4.3 Transient T	X	X	X	X	X	X	X		
5.0 Atmospherics									
5.1 Aero. Drag						X			X
5.2 Atm. Heating						X			
5.3 Pressure						X			
6.0 Mechanical									
6.1 Deploy. Motion	X	X			X		X		
6.2 Launch Vib.	X	X	X		X	X	X		X
6.3 Gravity Gradient	X				X				
7.0 Imagery									

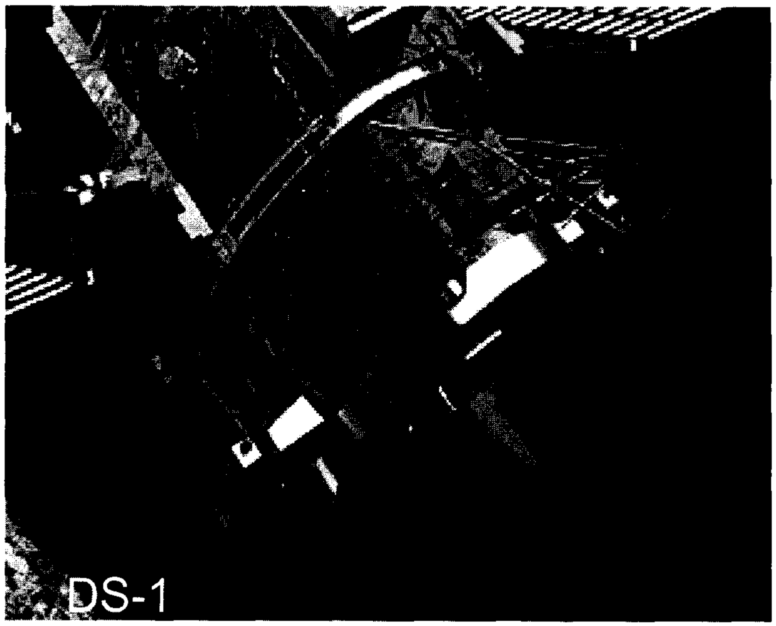
Currently the ST9 technology requirements are being formulated.

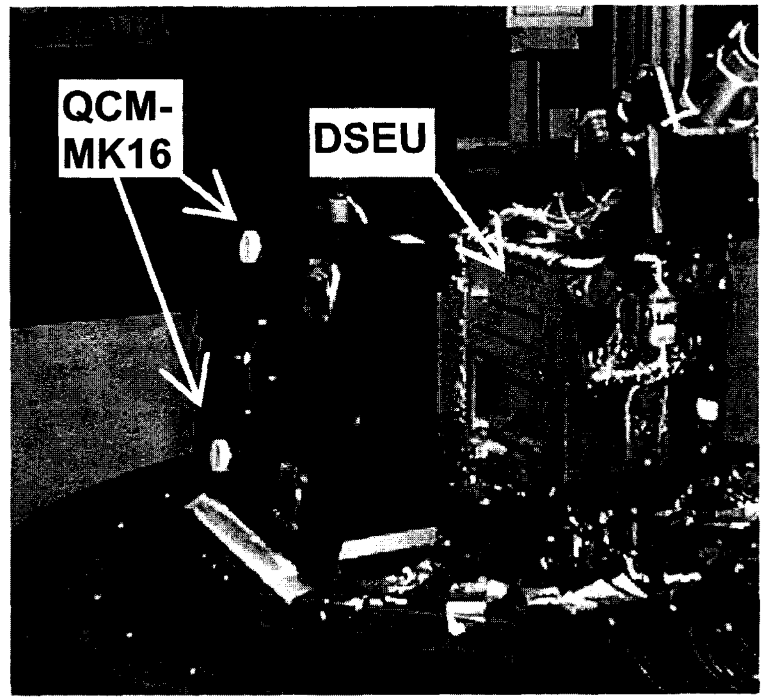
Space Environmental Effects on Membrane Materials



Based on: C. R. McInnes, "Solar Sailing: Technology, Dynamics and Mission Applications", Praxis Publishing (Chichester, UK, 1999)

DS-1 RSU: Remote Sensor Unit: QCM





Mass Sensitivity: 4.43 ng/cm^2-Hz

Range: 0 to 500 µg/cm^2

Resolution: 0.005 µg/cm^2

Data collected by Diagnostic Sensors Electronics Unit (DSEU) and derived from SAMMES.

D. E. Brinza, et. al., "An Overview of Results from the Ion Diagnostics Sensors flown on DS1," AIAA-2001-0966, 39th AIAA Aerospace Sciences Meeting 2001.

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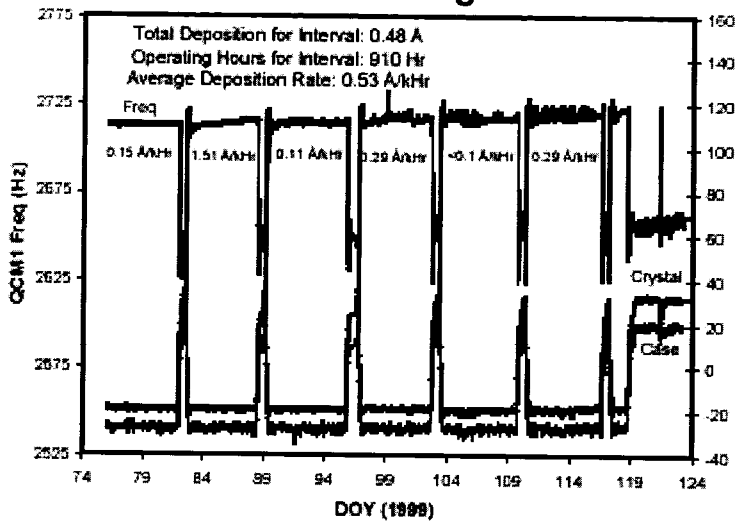
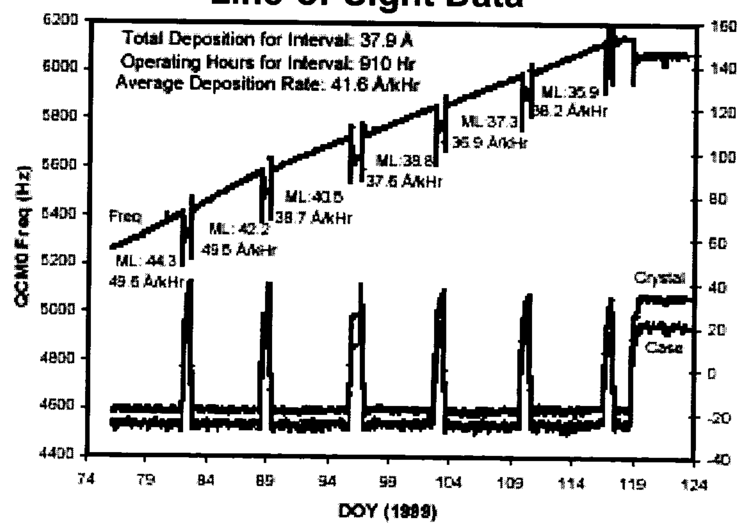
DS-1 Ion Thruster QCM Data

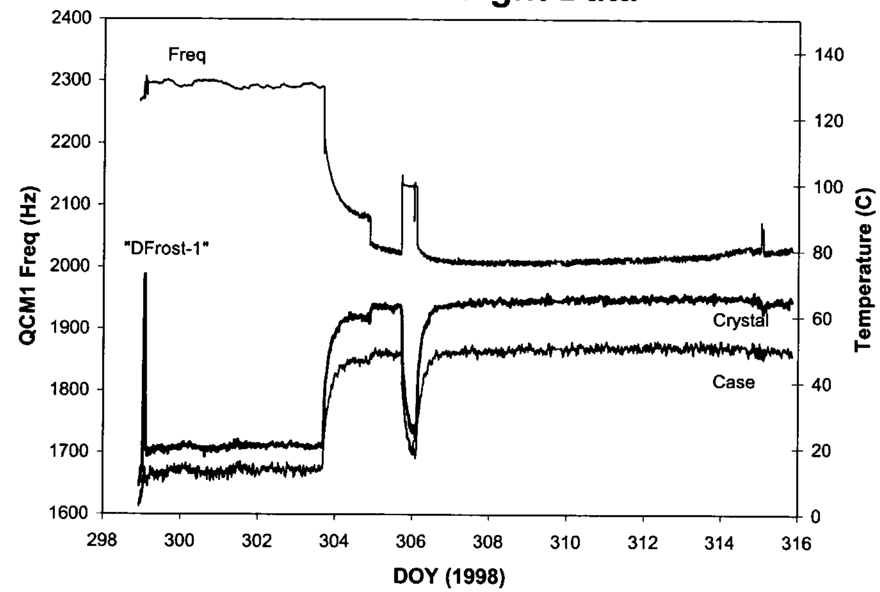
Non-Line-of-Sight Data



Line-of-Sight Data



Non-Line-of-Sight Data



Above: Determined launch contamination to be 8 nm.

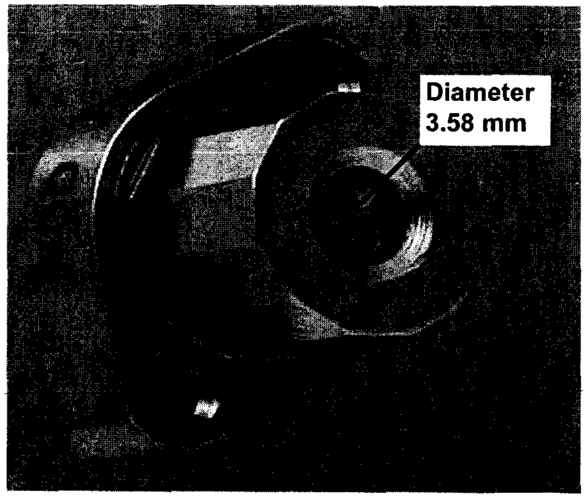
Left: Molybdenum deposition: ~4 nm/1000 hr

To extract contamination information, the QCM data must be corrected for temperature and solar illumination changes.

Quartz Crystal Microbalance: QCM (MK21)

Device:

Mass loading of the quartz crystal changes the resonant frequency.



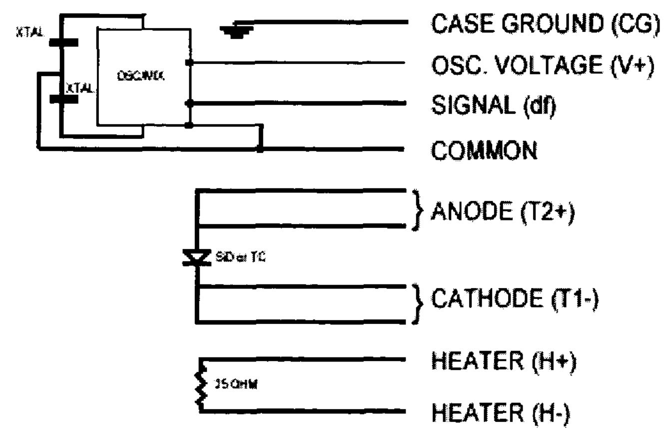
Manufacture:

Cost: 20 – 25 k$
Manufacturer: QCM Research,
Notes: Space qualified for JPL Pathfinder Rover and DS-1

Specifications

PARAMETER	UNITS	VALUE
Sensor range	g cm-2	> 10 -4 g cm-2
Temp. Sensitivity	Hz/°C	<2.5
Temp. Range	°C	-43 to +80
Temp. Accuracy	°C	<±1
Temp. Precision	°C	<±0.2
Sensor Output	kbps	0.001
Sensitivity	ng cm-2	> 4.4 ng cm-2

Circuitry



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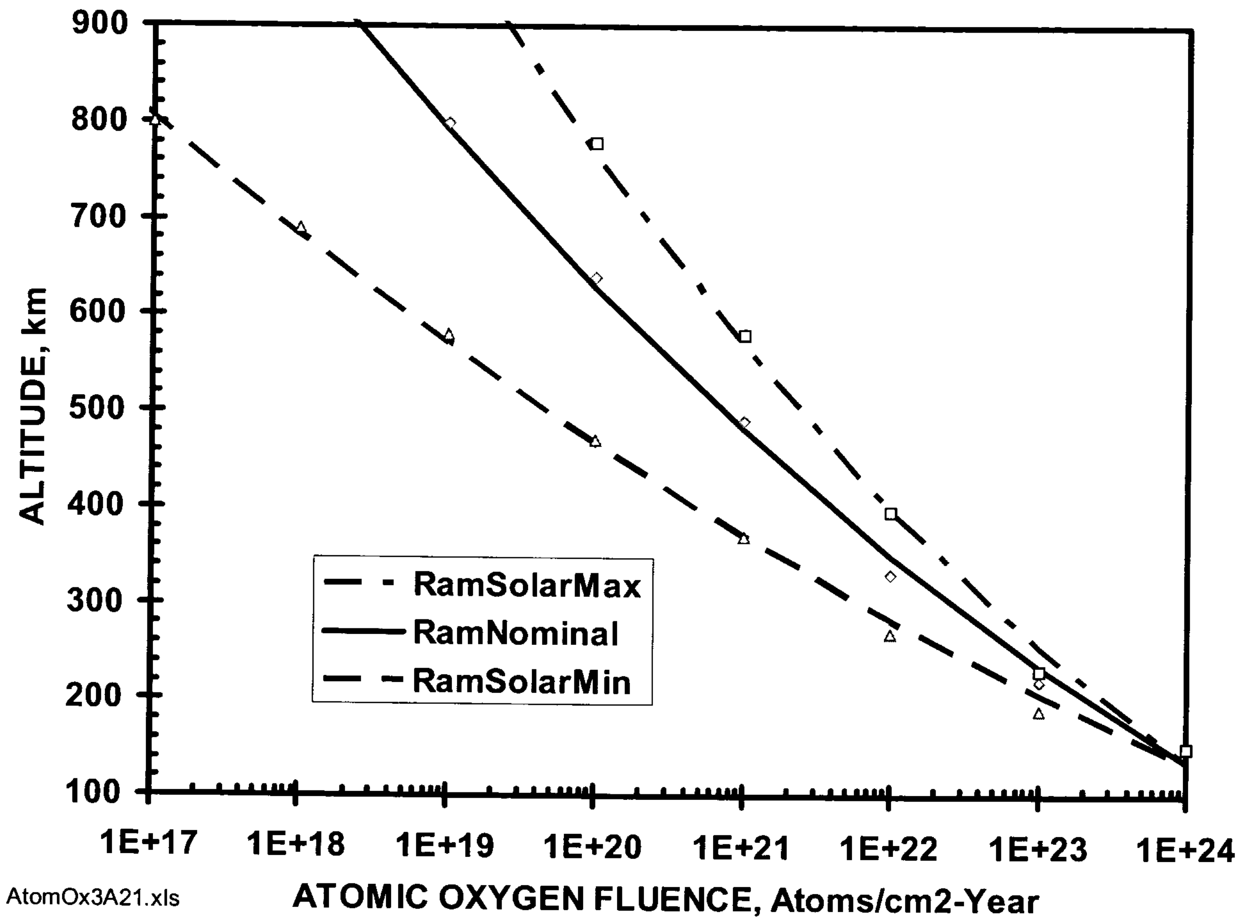
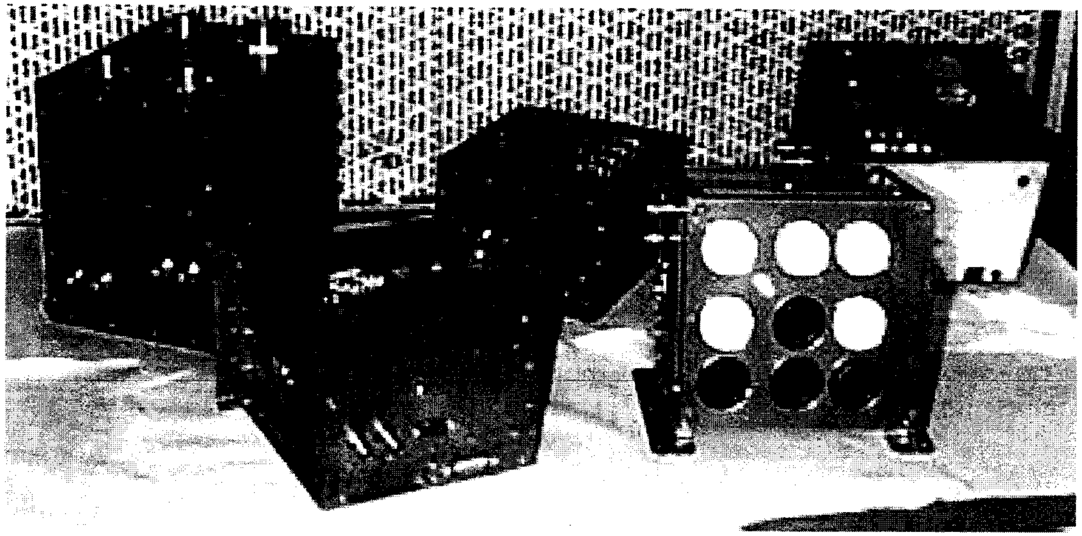
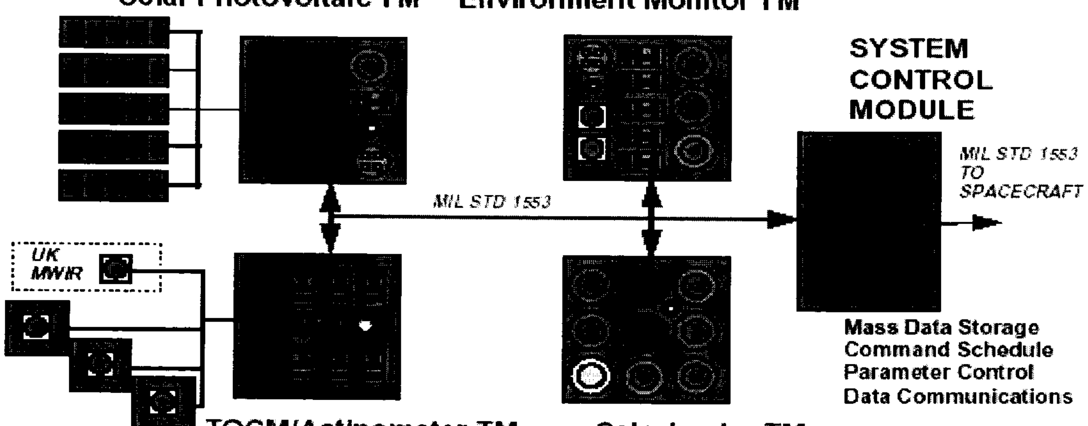
Atomic Oxygen



After: L. L. Ledger and J. T. A. Visentine, "A consideration of atomic oxygen interactions with the space station," J. of Spacecraft and Rockets ,Vol. 23, 323-330, 1986.

SAMMES:
Space Active Modular Materials Experiment





Flight: STRV-2 (2000)
Mass: ~12 kg
Power: ~ 10 W

Sensor Suit:
- **Actinometer (AO)**
- **Calorimeter**
- **QCM**
- **Radiation Dosimeter**
- **Sun Position Sensor**
- **Sun Sensor**
- **Solar Cell Strings**

After: P. B. Joshi, M. R. Malonson, B. D. Green, J. McKay, D. Brinza, and G. Arnold, "Spacecraft Environment and Effects Monitoring Instrumentation for Small Satellites", J. of Spacecraft and Rockets Vol. 35, No. 6, Nov 1998.

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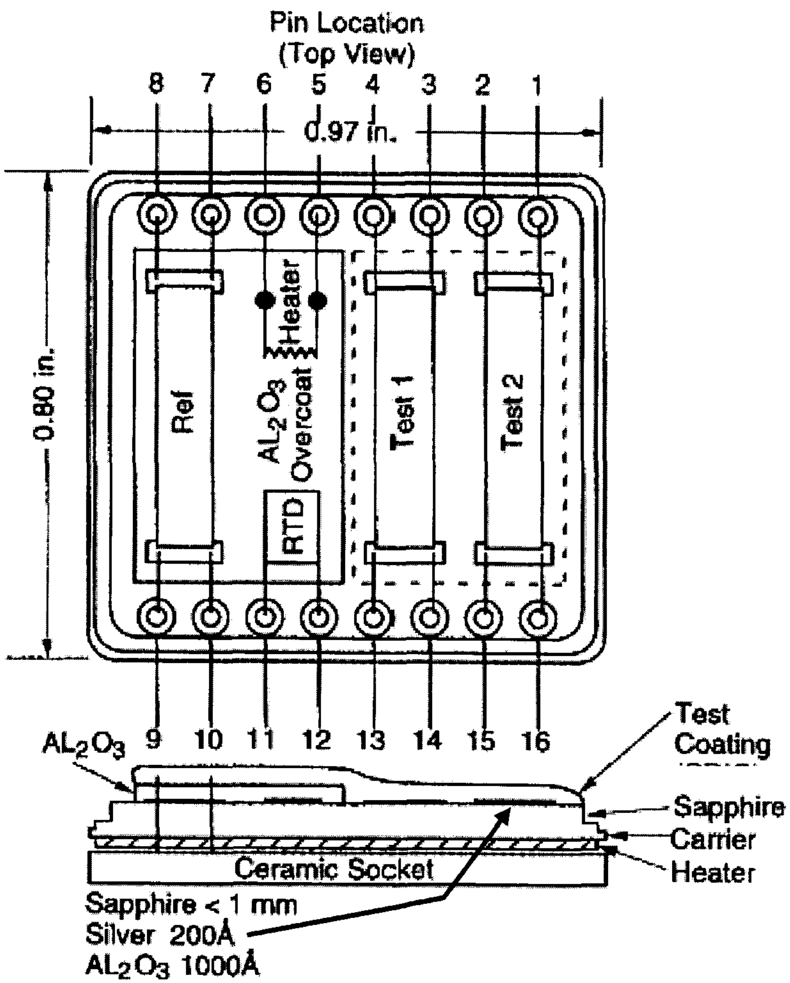
Atomic Oxygen: Actinometer



Device:

Silver resistor is oxidized by the AO.
Carbon resistor is eroded by the AO.

Manufacture:

Cost: TBD
Manufacturer: JPL
Flight Validation: Mat-Lab Experiment on Wake Shield Facility 1 (STS-60)

Specifications

PARAMETER	UNITS	VALUE
Range	Atoms/cm^2-year	10^{16} to 10^{22}
Resistor-Silver	Ohms	1 to 100
Resistor-Carbon	Ohms	1k to 100k
Temperature: Range	°C	-50 to +80
Temperature: Accuracy	°C	±1
Sensor Output	kbps	0.01

After: P. B. Joshi, M. R. Malonson, B. D. Green, J. McKay, D. Brinza, and G. Arnold, “Spacecraft Environment and Effects Monitoring Instrumentation for Small Satellites”, J. of Spacecraft and Rockets Vol. 35, No. 6, Nov 1998.

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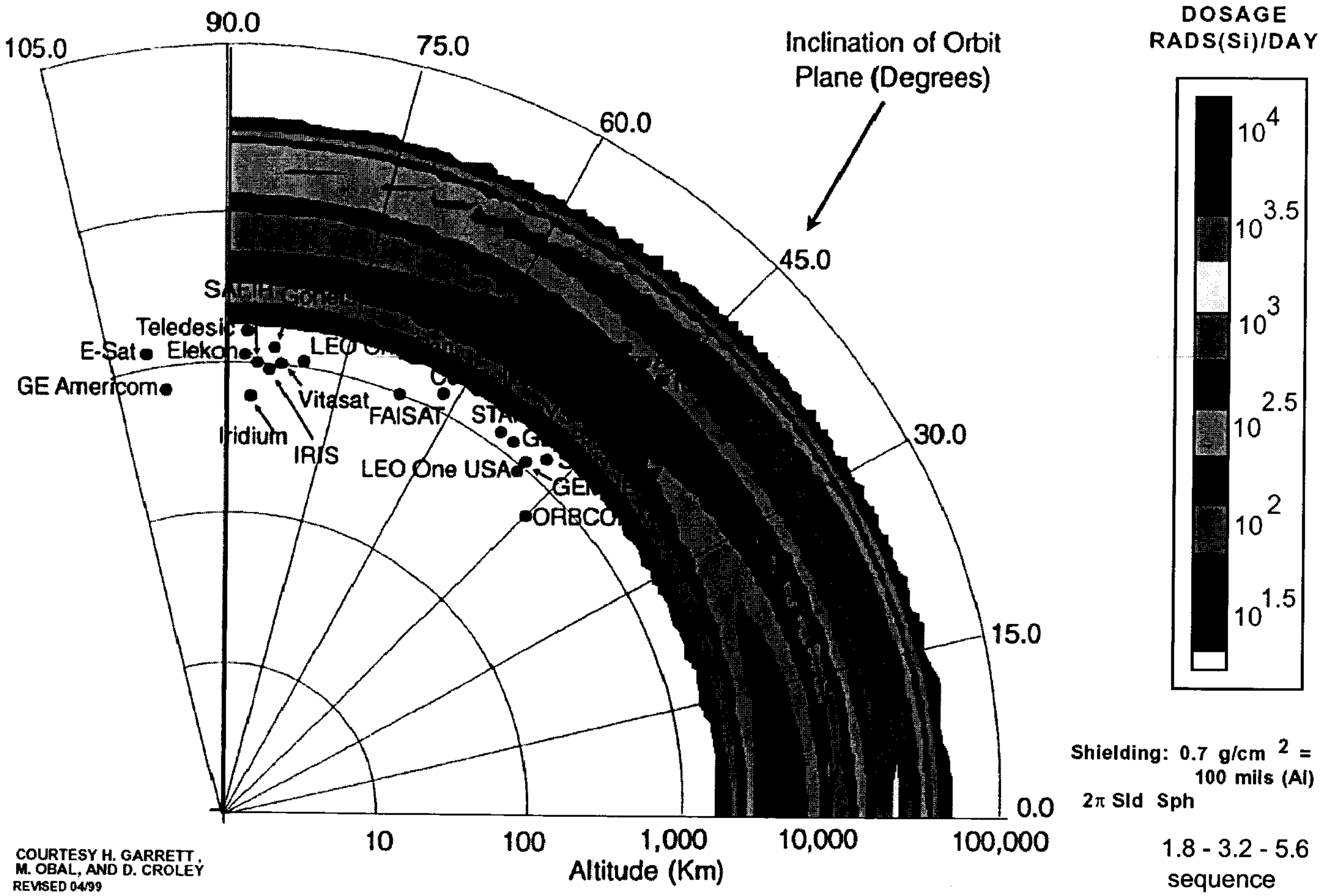
Total Ionizing Dose for Circular Orbits

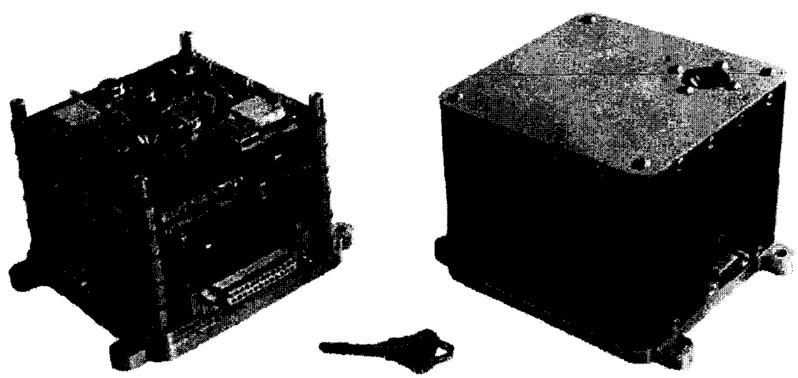


NMP space validation flights will be found in orbits between the Earth-Moon. The duration will be between days to six months.

NMP Environmental Monitor: Preliminary Design Concept

Compact Environmental Anomaly Sensor (CEASE) - AFRL

Self-contained, autonomous device to warn of or identify the cause of anomalies resulting from the natural space environment.

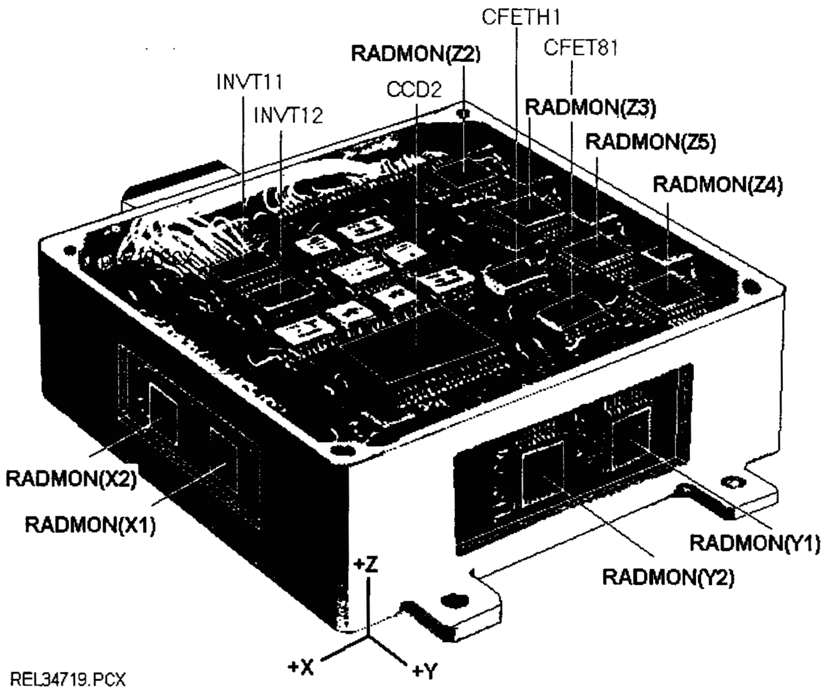


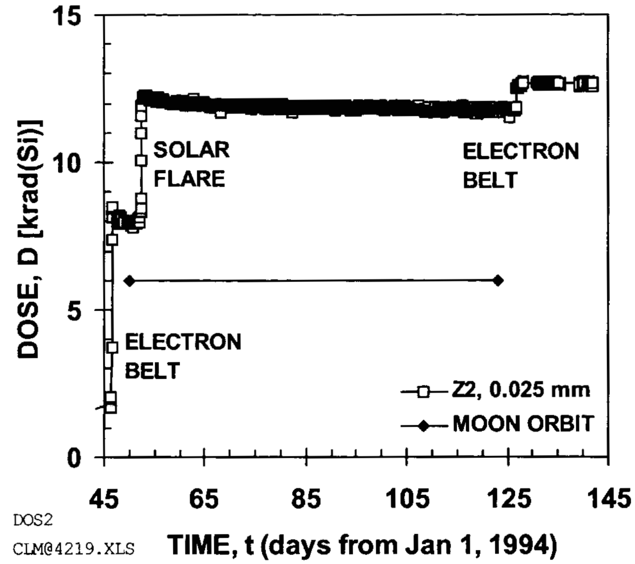
- Surface Charging
- Deep Dielectric Charging
- Single Event Upsets (SEU's)
- Radiation Dose Effects

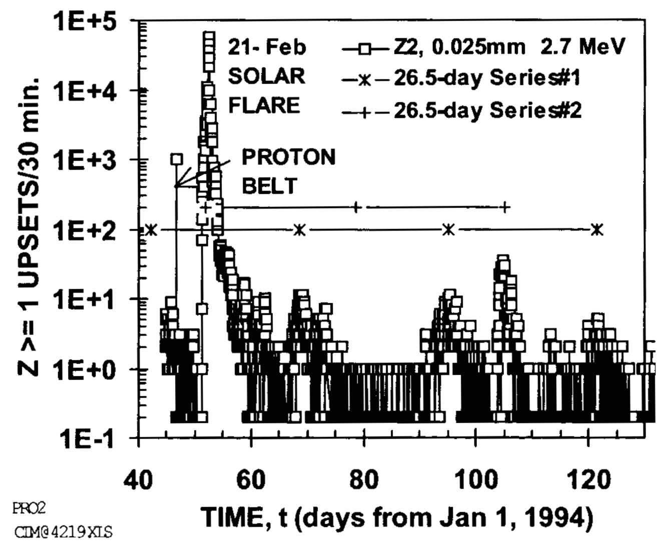
- Mass: 1 kg
- Volume: 10 x 10 x 8.2 cm^3
- Power: 1.5 W
- Telemetry: 1.3 bits per sec

- Protons: 1< E< 20 MeV
- Electrons:
  - 50 < E < 250 keV
  - E > 250 keV.

Radiation Test Package Flown on Clementine







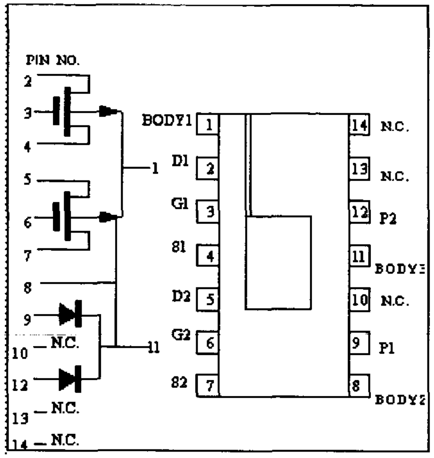
RRELAX is a 624 g, 2.4 watt, 10.2 cm x 10.2 cm x 3.8 cm box used to characterize 166 test devices and the electron, proton, solar flare environment.

After: M. G. Buehler, G. A. Soli, B. R. Blaes, J. M. Ratliff, and H. B. Garrett, “Clementine RRELAX SRAM Particle Spectrometer”, IEEE Trans. on Nuclear Science, Vol. 41, No. 6, 2404-24011, December 1994

RADFET 4kÅ Unimplanted DOSIMETER

Device:

Ionizing radiation dose measurements by detecting change in gate voltage threshold.



Manufacture:

Cost: TBD

Manufacturer: NMRC

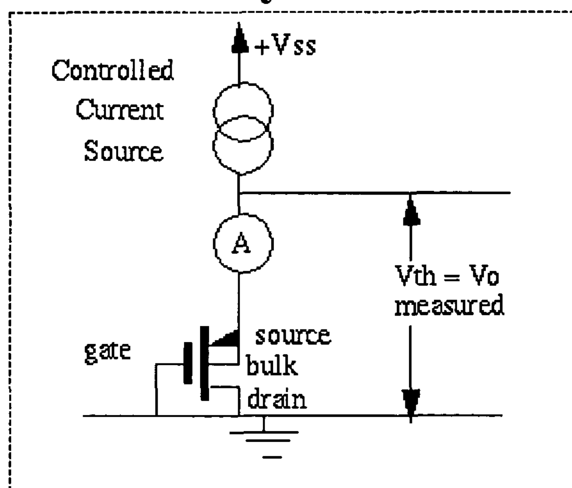
Notes:

Function: Ionizing radiation dose measurements by detecting change in gate voltage threshold.

Specifications

PARAMETER	UNITS	VALUE
Dose: Range	krad	0.1 to 50
Range	krad	0.1 to 50
Sensitivity	mV/rad	0.2
Temp. Sensitivity	krad/°C	0.001
Sensor Output	kbps	0.01

Circuitry



Operate FET at the temperature-independent current point. Temperature compensation/drift/fading are considerations

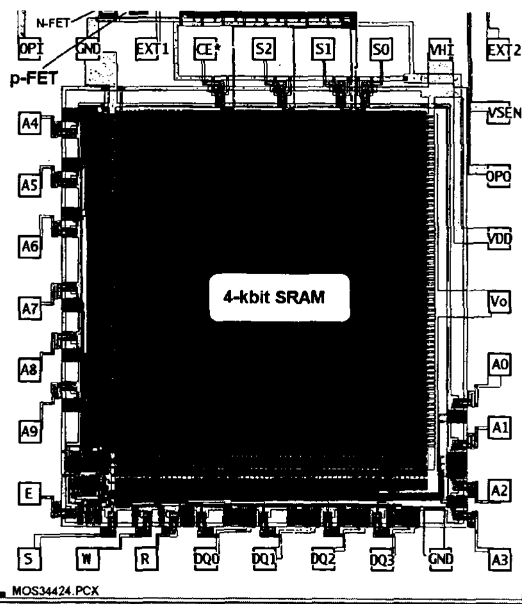
SINGLE-EVENT UPSETS

Commercially available DRAM detector with FPGA controller

DRAM Specifications

PARAMETER	UNITS	VALUE
Upset: Rate Range	Upsets/bit-s	<0.02
Upset: Threshold	MeV-cm2/mg	>1
Rad Hard	krad	20
Sensor Output	kbps	0.01
Total Bits	Bits	3.4
Manufacturer	--	Micron, Xylinks

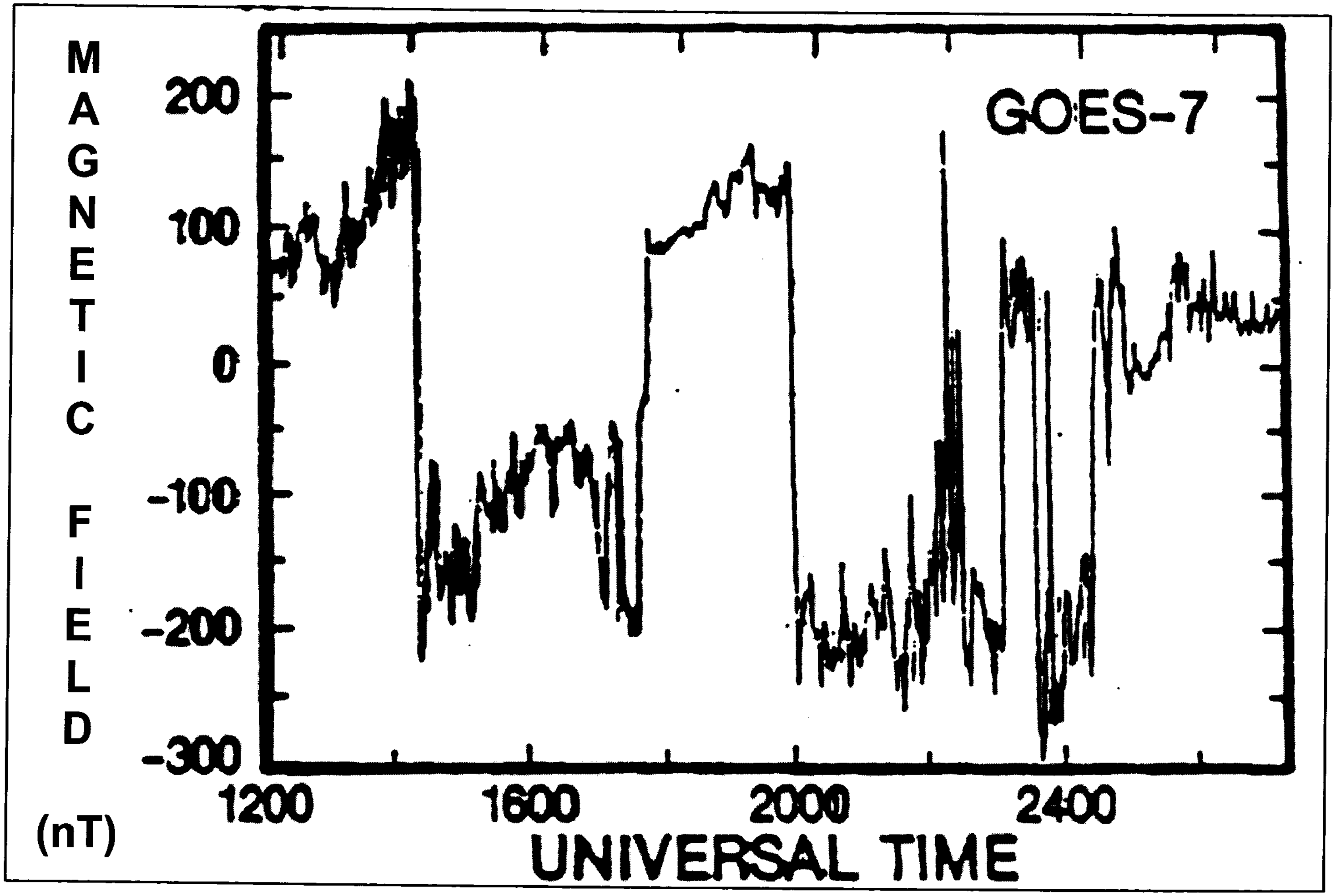
Upsetable SRAM CHIP



SRAM Specifications

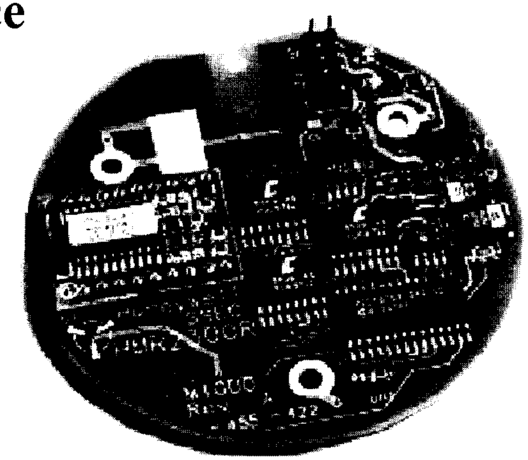
PARAMETER	UNITS	VALUE
Upset: Rate Range	Upsets/bit-s	<0.02
Upset: Threshold	MeV-cm2/mg	>1
Rad Hard	krad	20
Sensor Output	kbps	0.01
Total Bits	Bits	4K
Manufacturer	--	JPL/MOSIS

Magnetic Field



Honeywell 3-Axis Magnetometer

Device



7.2 cm

Purpose:

- Detect EMI
- Spacecraft Attitude

Manufacture:

- **Cost: $800**
- **Lead Time:** 6 weeks
- **Manufacturer:** Honeywell Solid State Electronics Center,
- **Notes:** MIL-STD 810E qual for military and commercial grade
- **Power Requirements:** 6-15V Supply Voltage @ 45 mA
- **Interfaces:** RS422 or RS485

Magnetic Cleanliness:

The presence of ferrous materials—such as nickel, iron, steel, cobalt—near the magnetometer will create disturbances in the earth's magnetic field that will distort x, y and z field measurements.

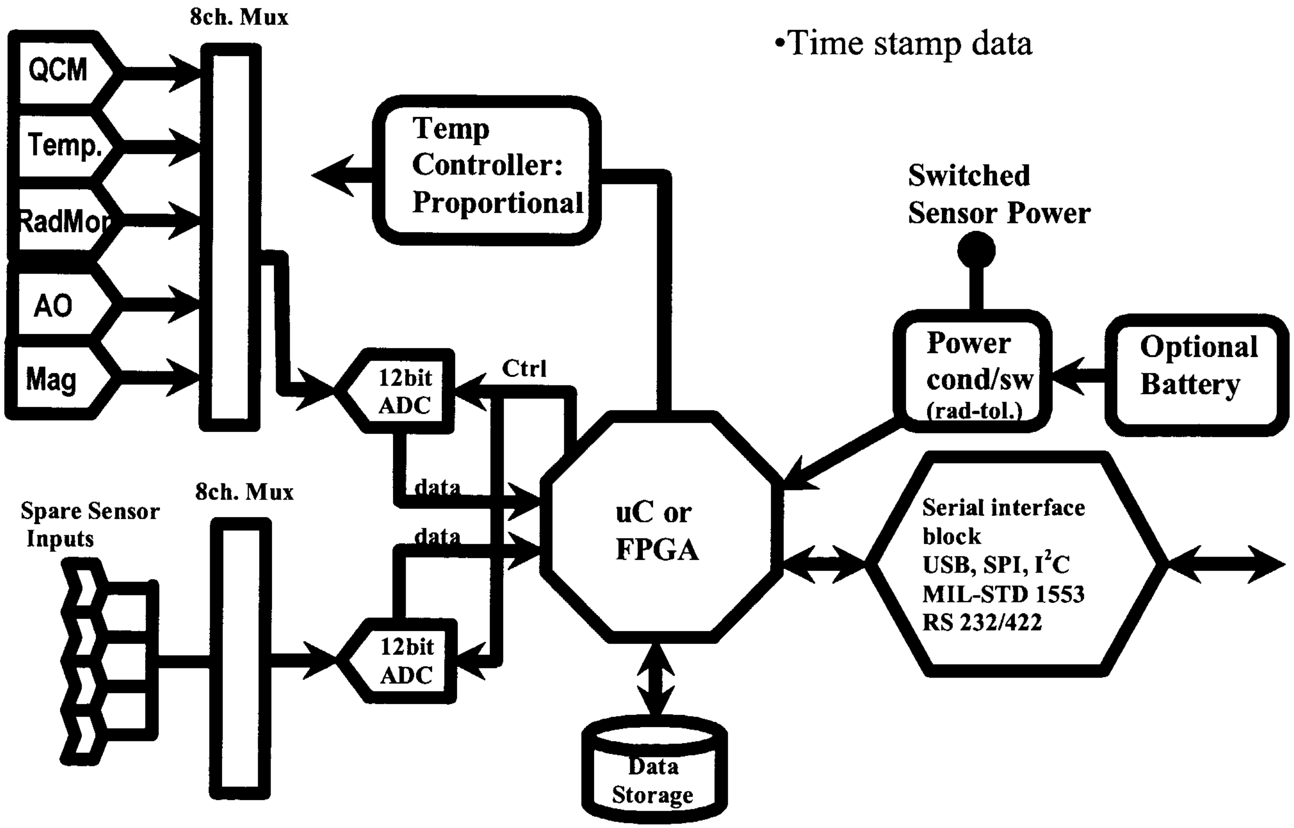
Specifications

PARAMETER	UNITS	VALUE
Magnetic Field	μT	±20
Resolution	nT	<7
Sensor Output	kbps	0.15

Prototype EM Circuitry

Attributes:

- Flexible sensors and spacecraft Interfaces
- Local non-volatile data storage.
- Time stamp data



Environmental Monitor: Conclusion and Plans

1. Commercially available sensors can be used to assemble an Environmental Monitor by an integrator.
2. Further define:
   - Requirements
   - Operating scenarios
   - Testing.
3. Prepare an RFP.